ELVL-2023-0046530
April 17, 2023

# Orbital Debris Assessment for
# The BLAST CubeSat
# per NASA-STD 8719.14C

Signature Page

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Reply to Attn of: VA-H1

TO: Liam Cheney, LSP Mission Manager, NASA/KSC/VA-C

FROM: Mike Perotti, NASA/KSC/VA-H1

SUBJECT: Orbital Debris Assessment Report (ODAR) for the BLAST CubeSat

REFERENCES:

A. *NASA Procedural Requirements for Limiting Orbital Debris Generation*, NPR 8715.6B, 6 February 2017
B. *Process for Limiting Orbital Debris*, NASA-STD-8719.14B, 25 April 2019
C. International Space Station Reference Trajectory, delivered December 2019
D. McKissock, Barbara, Patricia Loyselle, and Elisa Vogel. *Guidelines on Lithium-ion Battery Use in Space Applications*. Tech. no. RP-08-75. NASA Glenn Research Center Cleveland, Ohio
E. *UL Standard for Safety for Lithium Batteries, UL 1642*. UL Standard. 5th ed. Northbrook, IL, Underwriters Laboratories, 2012
F. Kwas, Robert. Thermal Analysis of ELaNa-4 CubeSat Batteries, ELVL-2012-0043254; Nov 2012
G. Range Safety User Requirements Manual Volume 3- Launch Vehicles, Payloads, and Ground Support Systems Requirements, AFSCM 91-710 V3.
H. HQ OSMA Policy Memo/Email to 8719.14: CubeSat Battery Non-Passivation, Suzanne Aleman to Justin Treptow, 10, March 2014
I. ODPO Guidance Email: Fasteners and Screws, John Opiela to Yusef Johnson, 12 February 2020
J. Debris Assessment Software User's Guide: Version 3.2, NASA/TP-2019-220300

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the Bouchet Low-Earth Alpha-Beta Space Telescope (BLAST) CubeSat launching on the SpX-30 Mission. It serves as the final submittal in support of the spacecraft Safety and Mission Success Review (SMSR). Sections 1 through 8 of ref. (b) are addressed in this document; sections 9 through 14 fall under the requirements levied on the primary mission and are not presented here.

This CubeSat will passively reenter, and therefore this ODAR will also serve as the End of Mission Plan (EOMP) for this CubeSat.

| RECORD OF REVISIONS | | |
|---|---|---|
| **REV** | **DESCRIPTION** | **DATE** |
| 0 | Original submission | April 2023 |

## Section 1: Program Management and Mission Overview

BLAST is sponsored by the Space Operations Mission Directorate at NASA Headquarters. The Program Executive is Michael Rodelo. Responsible program/project manager and senior scientific and management personnel are as follows:

Andrew Szymkowiak, Yale University
Dr. Larry Wilen, Yale University

The following table summarizes the compliance status of BLAST, which will be flown on the SPX-30 mission to the International Space Station. The current launch date is planned for no earlier than 03/04/2024. DAS version 3.2.3 was used to generate the data provided in this document. BLAST is fully compliant with all applicable requirements.

**Table 1: Orbital Debris Requirement Compliance Matrix**

| Requirement | Compliance Assessment | Comments |
|---|---|---|
| 4.3-1a | Not applicable | No planned debris release |
| 4.3-1b | Not applicable | No planned debris release |
| 4.3-2 | Not applicable | No planned debris release |
| 4.4-1 | Compliant | On board energy source (batteries) incapable of debris-producing failure |
| 4.4-2 | Compliant | On board energy source (batteries) incapable of debris-producing failure |
| 4.4-3 | Not applicable | No planned breakups |
| 4.4-4 | Not applicable | No planned breakups |
| 4.5-1 | Compliant | |
| 4.5-2 | Not applicable | |
| 4.6-1(a) | Compliant | 0.79 years |
| 4.6-1(b) | Not applicable | |
| 4.6-1(c) | Not applicable | |
| 4.6-2 | Not applicable | |
| 4.6-3 | Not applicable | |
| 4.6-4 | Not applicable | Passive disposal |
| 4.6-5 | Compliant | |
| 4.7-1 | Compliant | Non-credible risk of human casualty |
| 4.8-1 | Compliant | No planned tether releases |

## Section 2: Spacecraft Description

Table 2 outlines its generic attributes.

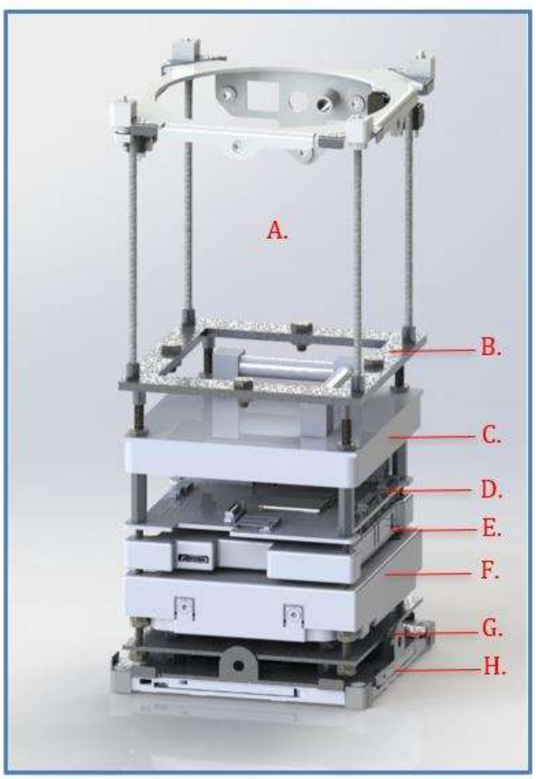
**Table 2: BLAST Attributes**

| CubeSat Names | CubeSat Quantity | CubeSat size (mm) | CubeSat Mass (kg) |
|---|---|---|---|
| BLAST | 1 | 106 x 106 x 223 | 3.121 |

The following pages describe the BLAST CubeSat.

## BLAST – Missouri Science & Technology University – 3U


**Figure 1: BLAST View: As-Ejected**




Internal components of the CubeSat housed within a custom-built bussing system

A. Space for gravity-gradient boom, magnetometer, cosmic ray detector, and sun sensor
B. Separation plate
C. Magnetorquer
D. OBC
E. Transceiver
F. Battery
G. Separation plate
H. Antenna

**Figure 2: BLAST Expanded View**

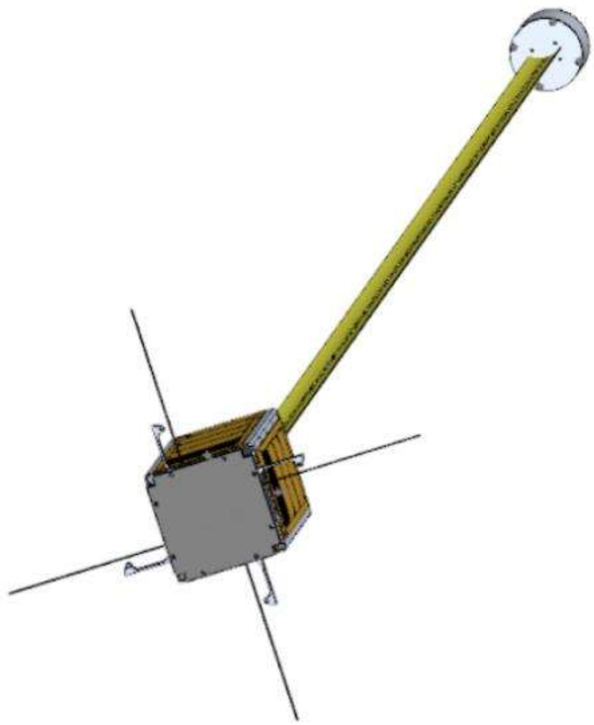


**Figure 3: BLAST Deployed View**

## Overview

BLAST is a scientific investigation mission to map the distribution of galactic cosmic radiation across the night sky. The satellite will identify and count alpha particles and beta particles in the rays, and measure the radiation energy around Earth. BLAST will contribute to the ongoing search for the origins and nature of these rays, which will provide insight into the origins of the universe.

## CONOPS

Upon deployment from the ISS, BLAST will power up and begin a timer countdown. After 30 minutes have elapsed the antenna will deploy and at 45 minutes the satellite will attempt to detect radio transmissions from Yale's ground station. This may take several attempts. During this time, the satellite will also make measurements of roll, pitch, and yaw using its magnetometer and sun sensor. Hysteresis rods will gradually dampen the tumble rate until it decreases to a pre-determined value. When the roll rate reaches this desired value, it will be safe for the gravity gradient boom to deploy. This will further dampen the roll rate and will eventually stabilize the satellite in the desired equilibrium orientation with the tip of the boom facing towards the Earth. When the satellite's passive ADCS systems have detumbled the satellite as much as possible, smaller attitude adjustments will be made by the magnetorquer. When the satellite has fully detumbled after several days, the computer will begin recording measurements from the onboard cosmic ray detector. These measurements will be transmitted to the Yale ground station during each pass or to the SatNOGS ground station network.

## Materials

BLAST uses a titanium 2U chassis by Pumpkin Aerospace. It will have non-deployable solar panels from Pumpkin Aerospace on 3.5 of its faces. Its UHF antenna and transceiver are both from EnduroSat, as is the OBC and Li-Po battery. It contains other COTS components as well as PCBs.

## Hazards

There are no radioactive materials, propellants, or other pressurized vessels on the satellite.

## Batteries

BLAST uses a commercial off-the-shelf electrical power system, EPS I from EnduroSat which has one integrated Li-Po battery pack and consists of two Li-Po battery cells connected in parallel. Each battery cell within the battery pack has an integrated Protection Circuit Module (PCM) which prevents over-current, over-charge, and over-discharge. The battery pack voltage and power are 3.7V nominal and 10.2 Wh, respectively. The UL listing number of the Li-Po batteries is BBCV2.MH13654.

## Section 3: Assessment of Spacecraft Debris Released during Normal Operations

The assessment of spacecraft debris requires the identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material.

Section 3 requires rationale/necessity for release of each object, time of release of each object, relative to launch time, release velocity of each object with respect to spacecraft, expected orbital parameters (apogee, perigee, and inclination) of each object after release, calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO), and an assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2.

No releases are planned on the BLAST CubeSat therefore this section is not applicable.

## Section 4: Assessment of Spacecraft Intentional Breakups and Potential for Explosions.

There are no plans for designed spacecraft breakups, explosions, or intentional collisions for BLAST.

As discussed in Reference H, with respect to 3U and smaller CubeSats, the probability of battery explosion is very low, and, due to the very small mass of the satellites and their short orbital lifetimes the effect of an explosion on the far-term LEO environment is negligible.

The CubeSat batteries still meet Req. 56450 (4.4-2) by virtue of the HQ OSMA policy regarding CubeSat battery disconnect stating;

> "CubeSats as a satellite class need not disconnect their batteries if flown in LEO with orbital lifetimes less than 25 years." (ref. (h))

Limitations in space and mass prevent the inclusion of the necessary resources to disconnect the battery or the solar arrays at EOM. However, the low charges and small battery cells on the CubeSat's power system prevent a catastrophic failure, so that passivation at EOM is not necessary to prevent an explosion or deflagration large enough to release orbital debris.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a maximum lifetime of 0.79 years maximum, BLAST is compliant.

## Section 5: Assessment of Spacecraft Potential for On-Orbit Collisions

Calculation of spacecraft probability of collision with space objects larger than 10 cm in diameter during the orbital lifetime of the spacecraft takes into account both the mean cross sectional area and orbital lifetime.

$$\boldsymbol{Mean\ CSA = \frac{\sum Surface\ Area}{4} = \frac{2 * [(w * l) + (w * h) + (l * h)]}{4}}$$

**Equation 1: Mean Cross Sectional Area for Convex Objects**

$$\boldsymbol{Mean\ CSA = \frac{(A_{max} + A_1 + A_1)}{2}}$$

**Equation 2: Mean Cross Sectional Area for Complex Objects**

The CubeSat evaluated for this ODAR is stowed in a convex configuration, indicating there are no elements of the CubeSat obscuring another element of the same CubeSat from view. Thus, the mean CSA for the stowed CubeSat was calculated using $\boldsymbol{Mean\ CSA = \frac{\sum Surface\ Area}{4} = \frac{2*[(w*l)+(w*h)+(l*h)]}{4}}$ Equation 1. This configuration renders the longest orbital life times for all CubeSats.

Once a CubeSat has been ejected from the CubeSat dispenser and deployables have been extended, Equation 2 is utilized to determine the mean CSA. $A_{max}$ is identified as the view that yields the maximum cross-sectional area. $A_1$ and $A_2$ are the two cross-sectional areas orthogonal to $A_{max}$. Refer to Appendix A for component dimensions used in these calculations

BLAST's expected orbit at deployment has a 408.2 -km perigee and a 424.0-km apogee at a 51.6° inclination. With an area to mass ratio of 0.0094 $m^2$/kg, DAS yields 0.79 years for orbit lifetime for its as-ejected state, which in turn is used to obtain the collision probability. BLAST is calculated to have a maximum probability of collision of 1.19E-7. Table 3 below provides complete results.

| CubeSat | | BLAST |
|---|---|---|
| | **Mass (kg)** | 3.121 |
| As-Ejected | **Mean C/S Area ($m^2$)** | 0.0293 |
| | **Area-to Mass ($m^2$/kg)** | 0.0094 |
| | **Orbital Lifetime (yrs)** | **0.79** |
| | **Probability of collision ($10^{-7}$)** | **0.517** |
| Deployed | **Mean C/S Area ($m^2$)** | 0.0674 |
| | **Area-to Mass ($m^2$/kg)** | 0.0216 |
| | **Orbital Lifetime (yrs)** | **0.36** |
| | **Probability of collision ($10^{-7}$)** | **1.19** |

Solar Flux Table Dated 12/19/2022

**Table 3: CubeSat Orbital Lifetime & Collision Probability**

The probability of BLAST colliding with debris or meteoroids greater than 10 cm in diameter that are capable of preventing post-mission disposal is less than 0.0000001, for any configuration. This satisfies the 0.001 maximum probability requirement 4.5-1.

Assessment of spacecraft compliance with Requirements 4.5-1 shows BLAST to be compliant.

This ODAR also serves as the EOMP (End of Mission Plan).

**Section 6: Assessment of Spacecraft Post-Mission Disposal Plans and Procedures**

BLAST will naturally decay from orbit within 25 years after end of the mission, satisfying requirement 4.6-1a detailing the spacecraft disposal option.

Planning for spacecraft maneuvers to accomplish post-mission disposal is not applicable. Disposal will be achieved via passive atmospheric reentry and does not have a deorbit device.

Calculating the area-to-mass ratio for the worst-case (smallest Area-to-Mass) post-mission disposal finds BLAST in its stowed configuration as the worst case. The area-to-mass is calculated as follows:

$$\frac{\boldsymbol{Mean}\ {}^{\boldsymbol{C}}\!/_{\boldsymbol{S}}\,\boldsymbol{Area}\ (\boldsymbol{m^2})}{\boldsymbol{Mass}\ (\boldsymbol{kg})} = \boldsymbol{Area-to-Mass}\ (\frac{\boldsymbol{m^2}}{\boldsymbol{kg}})$$

**Equation 3: Area to Mass**

$$\frac{0.0293\ m^2}{3.12kg} = 0.0094\frac{m^2}{kg}$$

The assessment of the spacecraft illustrates it is compliant with Requirements 4.6-1 through 4.6-5.

<u>DAS Orbital Lifetime Calculations:</u>
DAS inputs are: 424.0-km maximum apogee and 408.2-km maximum perigee altitudes with an inclination of 51.6º at deployment no earlier than 3/4/2024. An area to mass ratio of ~0.0094 $m^2$/kg for the BLAST CubeSat was used. DAS yields a 0.79 years orbit lifetime for BLAST in its stowed state.

This meets requirement 4.6-1.

**Section 7: Assessment of Spacecraft Reentry Hazards**

A detailed assessment of the components to be flown on BLAST was performed. The assessment used DAS, a conservative tool used by the NASA Orbital Debris Office to verify Requirement 4.7-1. The analysis is intended to provide a bounding analysis for characterizing the survivability of a CubeSat's component during re-entry. For example, when DAS shows a component surviving reentry, it is not taking into account the material ablating away or charring due to oxidative heating. Both physical effects are experienced upon reentry and will decrease the mass and size of the real-life components as they reenter the atmosphere, reducing the risk they pose still further.

The following steps are used to identify and evaluate a component's potential reentry risk relative to the 4.7-1 requirement of having less than 15 J of kinetic energy and a 1:10,000 probability of a human casualty in the event it survives reentry.

1. Low melting temperature (less than 1000 °C) components are identified as materials that would never survive reentry and pose no risk of human casualty. This is confirmed through DAS analysis that showed materials with melting temperatures equal to or below that of copper (1080 °C) will always demise upon reentry for any size component up to the dimensions of a 1U CubeSat.
2. The remaining high temperature materials are shown to pose negligible risk of human casualty through a bounding DAS analysis of the highest temperature components, stainless steel (1500°C). If a component has a melting temperature between 1000 °C and 1500°C, it can be expected to possess the same negligible risk as a stainless steel component of similar dimensions.
3. Fasteners and similar materials that are composed of stainless steel or a lower melting point material will not be input into DAS, as suggested by guidance from the Orbital Debris Project Office (Reference I)

**Table 4: BLAST High Melting Temperature Material Analysis**

| Name | Material | Total Mass (kg) | Demise Alt (km) | Kinetic Energy (J) |
|---|---|---|---|---|
| Magnetorquer | Gold Element | 0.1976 | 76.3 | - |
| Tape Measure | Stainless Steel | 0.1234 | 0.0 | 1.02 |
| Boom Motor | Stainless Steel | 0.011 | 74.0 | - |

The majority of high melting point components demise upon reentry and BLAST complies with the 1:10,000 probability of Human Casualty Requirement 4.7-1. A breakdown of the determined probabilities follows:

**Table 5: Requirement 4.7-1 Compliance by CubeSat**

| Name | Status | Risk of Human Casualty |
|---|---|---|
| BLAST | Compliant | 1:100,000,000 |

*Requirement 4.7-1 Probability of Human Casualty ≤ 1:10,000

If a component survives to the ground but has less than 15 Joules of kinetic energy, it is not included in the Debris Casualty Area that inputs into the Probability of Human Casualty calculation. This is why BLAST has a 1:100,000,000 probability, as none of its components have more than 15J of energy.

BLAST is compliant with Requirement 4.7-1 of NASA-STD-8719.14A.

## Section 8: Assessment for Tether Missions

BLAST will not be deploying any tethers.

**Section 9-14**

ODAR sections 9 through 14 pertain to the launch vehicle, and are not covered here. Launch vehicle sections of the ODAR are the responsibility of the launch provider.

If you have any questions, please contact the undersigned at 321-205-4667.

/original signed by/

Mike Perotti
Flight Design Analyst
NASA/KSC/VA-H1

cc : VA-C/Liam J. Cheney
VA-C/Norman L. Phelps
AIS2/ Jennifer A. Snyder
SA-D1/Kevin R. Villa
SA-D2/Homero Hidalgo

## Appendix Index:

## **Appendix A.** BLAST Component List

| Item Number | Name | Qty | Material | Mass (g) (total) | Body Type | Diameter / Width (mm) | Length (mm) | Height (mm) | High Temp | Melting Temp (F°) | Survivability |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Total | 1 | | 3120.959 | Box | 106 | 106 | 223 | No | - | Demise |
| 2 | Chassis | 1 | Aluminum 5052-H32 | 130.9 | Plate | 100 | 100 | 205 | No | - | Demise |
| 3 | Base plate | 1 | Aluminum 5052-H32 | 36 | Plate | 100 | 100 | 45.5 | No | - | Demise |
| 4 | Large aperature base plate | 1 | Aluminum 5052-H32 | 35.2 | Plate | 100 | 100 | 32.9 | No | - | Demise |
| 5 | Bussing system threaded rod (short) (x2) | 2 | 316 Stainless Steel | 13.842 | Cylinder | 3 | 3 | 153 | No | - | Demise |
| 6 | Bussing system threaded rod (long) (x2) | 2 | 317 Stainless Steel | 18.492 | Cylinder | 3 | 3 | 204 | No | - | Demise |
| 7 | 1st Bussing system adapter plate | 1 | 6061 Aluminum | 26.52 | Plate | 9.66 | 9.58 | 2 | No | - | Demise |
| 8 | 2nd Bussing system adapter plate | 1 | 6061 Aluminum | 45.64 | Plate | 9.7 | 9.7 | 2 | No | - | Demise |
| 9 | M2.5 hex nut (x155) | 155 | 316 Stainless Steel | 43.555 | Cylinder | 2 | 5 | 5 | No | - | Demise |
| 10 | M3 hex nut (x80) | 80 | 316 Stainless Steel | 31.12 | Cylinder | 2.4 | 5.5 | 6.35 | No | - | Demise |
| 11 | M4 hex screw | 1 | 316 Stainless Steel | 0.095 | Cylinder | 7.5 | 7.5 | 8 | No | - | Demise |
| 12 | Solar panels (x3), sourced from Pumpkin Space | 3 | "Kapton™ coverlay, soldermask, Copper sheet, FR4 or other | 180 | Plate | 606 | 179.07 | 2.31 | No | - | Demise |
| 13 | Wires (x32) | 32 | Silver Coated Copper | 80 | Cylinder | 1.52 | 40 | 40 | No | - | Demise |
| 14 | Custom solar panel with aperture, sourced from Pumpkin Space | 1 | "Kapton™ coverlay, soldermask, Copper sheet, FR4 or other | 53 | Plate | 202 | 59.69 | 2.31 | No | - | Demise |
| 15 | Cosmic Ray Detector PCBs | 1 | FR-4, copper | 40 | Plate | 87 | 88.53 | 2 | No | - | Demise |
| 16 | Preamp (KETEK PEVAL-KIT MCX preamplifier) | 1 | aluminum | 47.7 | Box | 32 | 32 | 20 | No | - | Demise |
| 17 | Magnetorquer | 1 | Gold plated FR-4 (IPC-6012B), IPC – A600H class 3 assembly, soldering per ESA specification ECSS-Q-70-08 | 197.6g | Box | 90.3 | 95.9 | 12 | Yes | 1950 | Demise (76.3 km) |

| Item Number | Name | Qty | Material | Mass (g) (total) | Body Type | Diameter / Width (mm) | Length (mm) | Height (mm) | High Temp | Melting Temp (F°) | Survivability |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | Battery | 1 | Aluminum foil, metal oxide, binder, copper foil, carbon, electrolyte, 1,3-Propanesultone | 216 | Box | 88.2 | 93.9 | 13 | No | - | Demise |
| 19 | OBC | 1 | Propietary EnduroSat materials that follow CubeSat outgassing standards | 50 | Box | 1.6 | 97 | 97 | No | - | Demise |
| 20 | UHF Transceiver | 1 | Aluminum Plate 6061, | 90 | Plate | 79 | 77 | 9 | No | - | Demise |
| 21 | UHF Antenna | 1 | Aluminum with hard anodization, shape memory alloy, FR4 | 82.1 | Plate | 82.6 | 82.6 | 9.2 | No | - | Demise |
| 22 | Scintillator | 1 | polystyrene | 1 | Box | 10 | 10 | 10 | No | - | Demise |
| 23 | CRD shielding | 1 | Aluminum | 42.2 | Box | 41 | 19.41 | 28 | No | - | Demise |
| 24 | Tip mass | 1 | Aluminum, Lead | 1400 | Cylinder | 64.41 | 64.41 | 46.41 | No | - | Demise |
| 25 | Sprocket | 1 | Aluminum 6061 | 31.32 | Cylinder | 27.46 | 27.46 | 52 | No | - | Demise |
| 26 | Sprocket Pins (x6) | 1 | 52100 Alloy Steel | 0.78 | Cylinder | 13.44 | 13.44 | 47.16 | No | - | Demise |
| 27 | Spool | 1 | ABS, Steel | 98.7 | Cylinder | 51.44 | 51.44 | 23.53 | No | - | Demise |
| 28 | 572K222 Ball Bearing (x2) | 2 | 440C Stainless Steel, 304 Stainless Steel | 29.9 | Cylinder | 44 | 44 | 6.3 | No | - | Demise |
| 29 | Motor mount | 1 | Aluminum 6061 | 28.7 | Box | 30 | 54 | 16 | No | - | Demise |
| 30 | Back plate | 1 | Aluminum 6061 | 24.93 | Box | 11.46 | 30 | 37.5 | No | - | Demise |
| 31 | Side plate (x2) | 2 | Aluminum 6061 | 92 | Plate | 6.37 | 88.9 | 88.82 | No | - | Demise |
| 32 | Tape Measure | 1 | Stainless Steel | 123.42 | Cylinder | 57 | 57 | 9.25 | Yes | 2550 | Survives (1.0 J) |
| 33 | Threaded Rods M2.5 (x8) | 8 | 316 Stainless Steel | 13.52 | Cylinder | 2.39 | 2.39 | 505 | No | - | Demise |
| 34 | Lock Washers | 4 | 400 Series Stainless Steel | 0.016 | Cylinder | 0.16 | 2.35 | 2.35 | No | - | Demise |
| 35 | Set Screw for Motor Mount | 1 | Nylon | 0.009 | Cylinder | 2.84 | 2.3876 | 2.48 | No | - | Demise |
| 36 | Gravity Gradient Boom Motor (https://www.pololu.com/product/1595) | 1 | stainless steel, brass, carbon brushes | 10.5 | Box | 10 | 12 | 30 | Yes | 2550 | Demise (74.0 km) |

| Item Number | Name | Qty | Material | Mass (g) (total) | Body Type | Diameter / Width (mm) | Length (mm) | Height (mm) | High Temp | Melting Temp (F°) | Survivability |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 37 | motor encoder (https://www.pololu.com/product/4760) | 1 | FR-4, copper | 1.5 | Plate | 12.8 | 11.6 | 4 | No | - | Demise |
| 38 | Epoxy | 1 | J-B Weld 8265S Original Cold-Weld Steel Reinforced Epoxy | 5 | Cylinder | 10 | 10 | 10 | No | - | Demise |
| 39 | ThreadLocker | 1 | Loctite 271, 242 | 2 | Cylinder | 10 | 10 | 10 | No | - | Demise |